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THE VERITAS FACILITY: A VIRTUAL ENVIRONMENT PLATFORM FOR HUMAN PERFORMANCE RESEARCH

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14. ABSTRACT

The Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility is designed to support basic and applied research in complex multisensory environments including: 3D audio displays for improving safety in general aviation flight operations, advanced audio displays for improving performance in combat search and rescue missions, basic and applied research on multisensory (audio/visual/haptic) interactions, and displays for instrument landing systems. The central component of the facility is a CAVE®, a room-sized virtual environment presentation system. Several of our multi-user distributed experiments also utilized a virtual environment display system in the Appenzeller Visualization Laboratory (AVL). The facilities include a set of commercial-off-the-shelf (COTS) software solutions that work together with custom applications developed by our team to create immersive virtual environments. To facilitate software development and coherence, we created the Integrated Virtual Platform (IVP) as a flexible, expandable, and portable software platform for human performance experimentation. The experiments, experiences, and results in the VERITAS facility presented here, provide an example of a VE platform being actively used for human performance experimentation. The success of the research we have completed suggests that immersive virtual environments are useful tools in investigating complex human performance tasks.

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SUMMARY

The evaluation of advanced display concepts in operationally-relevant scenarios is critical for the accurate prediction of the effectiveness of such displays when they are ultimately employed in the battlespace. This document describes the development of an advanced, immersive, virtual environment facility (the VERITAS facility) and a flexible software architecture that, together, serve as a testbed for the rapid prototyping and evaluation of new display technologies developed by the Air Force Research Laboratory. In addition to describing the infrastructure, several experiments are described that demonstrate the capability, adaptability, and utility of this facility.

1. INTRODUCTION

While immersive virtual environments (VEs) are employed in applications ranging from entertainment and education to military training, their use for conducting human performance research is less prevalent. Such use holds great promise, as it affords researchers a means of generating realistic scenarios that capture the dynamics of a given situation while allowing for control over experimental variables and scenario timelines. With immersive VEs, advanced display concepts may be rapidly prototyped and tested, modified as needed, and re-tested in a cost-efficient manner. Moreover, extreme situations that would otherwise not be testable in the real world can be examined in VEs. In this paper we describe an immersive VE research facility being successfully used for human performance research along with several example experiments conducted in the facility.

The Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility is designed to support basic and applied research in complex multisensory environments. It is owned and operated by Wright State University (WSU) and located in the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base in Dayton Ohio. The facility is used for a wide range of human performance research projects including: 3D audio displays for improving safety in general aviation flight operations, advanced audio displays for improving performance in combat search and rescue missions, basic and applied research on multisensory (audio/visual/haptic) interactions, and displays for instrument landing systems. Our experience using the VERITAS facility in a wide range of applications has shown that a virtual environment is a viable and potent tool in human performance research.

2. GENERAL METHODS

2.1. Hardware

The central component of the VERITAS facility is a CAVE®, a room-sized virtual environment presentation system controlled by a cluster of Windows-based computers. High-resolution (1200x1200 pixel) stereoscopic images are rendered on 4 walls and the floor by Barco Galaxy NW-12 DLP projectors via RealD CrystalEyes shutter glasses. An Intersense IS-900 wireless tracking system monitors the position of the head and a handheld Wand, with the option of adding wired hand tracking. Originally built in 1997, the facility has gone through two major upgrades, including a conversion from CRT projectors to DLP, SGI UNIX computer to Windows PCs, and a wired magnetic tracking system to a wireless inertial/acoustic tracking system.

Several of the experiments presented here also utilized the Appenzeller Visualization Laboratory (AVL) located at WSU and owned and operated by the Wright State Research Institute (WSRI). The AVL contains a room-size, 4 projection-surface (3 walls and a floor) virtual environment display system (iSpace, Barco). High-resolution (1400x1050 pixel) stereoscopic images are rendered with Barco Galaxy NW-7 DLP projectors via RealD CrystalEyes shutter glasses. An optical tracking system (ARTTRACK) monitors the position of the head and handheld Flystick2. VERITAS and AVL are connected via an Internet2 wide area network (WAN) connection. We use the Distributed Interactive Simulation (DIS) or High-level architecture (HLA) messaging standards to communicate over this network, utilizing a DIS software router to send local DIS messages across the WAN to the other location. In both facilities, sounds are presented via Sennheiser HMD-280-XQ headsets, although loudspeakers have been used to generate an ambient acoustic environment (e.g., cockpit noise). A close-talking microphone mounted to the headsets allows subjects in the two facilities to talk to each other. The DIS radio protocol is used to transmit voice communications over the network.

2.2 Software

The facility includes a set of commercial-off-the-shelf (COTS) software solutions that work together with custom applications developed by our team to create immersive virtual environments. This COTS software includes Vega Prime (Presagis USA Inc., n.d.), VR-Forces (VT Mäk, n.d.), and trackd (Mechdyne Corporation, n.d.). When we first began using the CAVE for research we developed custom applications for each experiment, essentially starting from scratch each time. Later, to facilitate software development and coherence, scientists and engineers at WSU, AFRL, and WSRI created the Integrated Virtual Platform (IVP) as a flexible, expandable, and portable software platform for human performance experimentation (Fig. 1). The IVP consists of three core applications, the IVP Visual Environment (IVE), the IVP Audio Engine (IAE), and the IVP Controller (IC), along with complimentary software that handles artificial entities and data collection.

2.2.1 Visuals – IVE.

The IVE controls the subjects' visual experience in the IVP and allows the user to interact with the distributed virtual environment. It brings together what the users see, with tracking and locomotion capabilities, allowing users to perform tasks within the environment and interact with other entities (e.g., avatars). As a result of the lessons learned from years of software development in VERITAS, we found that in order to avoid latency problems and ensure synchronicity between environments that are physically separated, the IVE also needed to be responsible for a portion of the data collection tasks.

The current version of the IVE was developed in C++ using the Vega Prime API (Version 2.2.1) with the following add- on modules: Vega Immersive, Vega Prime Bonus Pack, vpNet, and DI-Guy. Vega Prime sits on top of OpenGL and provides all of the necessary scene graph functionality. Vega Immersive is a module that handles the field of view and tracking necessary to properly display the visual scene on the CAVE walls. The Vega Prime Bonus Pack adds extra classes for displaying text overlays on the screens. The vpNet module handles the DIS/HLA network messages in Vega Prime. DI-Guy is used to create the animated characters of all of the virtual humans and animals in the IVE (Boston Dynamic, n.d.). We use Visual Studio 2005 as the primary IDE for development (Microsoft Corporation, 2005).

We have five motion models that are part of the IVE, which define how users move within the virtual environments. It is possible to select among these via network or keyboard inputs. The CAVE and iSpace walking motion models are very similar. The user can rotate and view any azimuth in the CAVE by physically turning, and they can move by pointing the Wand in the desired direction of travel, but because the iSpace does not have a back wall, moving in that direction would be "blind." Therefore, we had to create a slightly different input method in which foot pedals allow users to rotate the world around themselves until they have a view of the desired direction of travel. The path following motion model allows for a preset path to be created offline and then followed by the user as if on rails. The helicopter motion model is similar to the path model but uses a predefined orbiting helicopter path that circles the origin of the terrain or the location of a defined entity in the scene, allowing for the helicopter rider to follow a ground entity around the terrain while orbiting the ground entity's position. The final motion model is the absence of motion; it is a static model placing the user at a specific location in the terrain, like a watchtower.

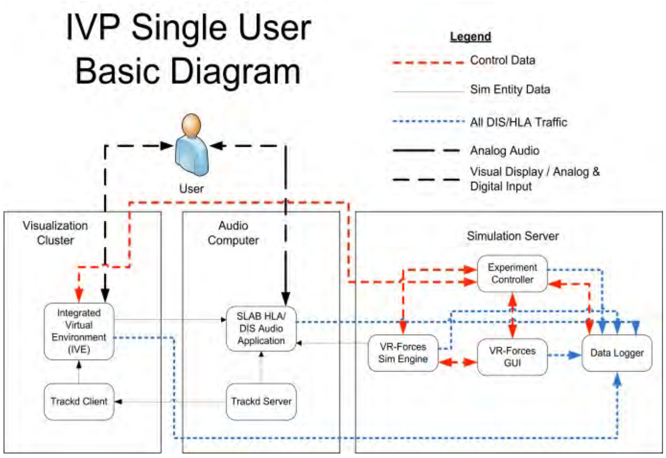

Figure 1. Diagram of the Integrated Virtual Platform

To provide interaction with the motion models and for collecting users' responses, we have implemented several input devices into the IVE. We have tracked input devices, an IS-900 Wand, an IS-900 Head tracker, an ART Head Tracker, and an ART Flystick2, which are connected to the IVP using the trackd software. A CH Products Pro Pedals USB is also used for the iSpace walking motion model and is connected via the DirectX API (Microsoft Corporation, 2004).

The IVP requires the applications running on different computers to communicate and synchronize in order to present a cohesive immersive virtual environment to the users. To accomplish this, the IVE has DIS/HLA support, and we created a set of custom control DIS protocol data units (PDUs) specific to the IVP. The IVE can be controlled via these PDUs through the IC application detailed below.

2.2.2 Audio - IAE

The IAE supports the audio environment that users experience during the course of an experiment. This includes environmental sounds, user-to-user communications, and/or signals received from a human command station and/or an automated server. This is the part of the architecture that supports the spatialization of incoming audio signals so that they are rendered from the correct location within the virtual environment. The IAE was developed for the IVP in C++/C# using the Sound Lab (SLAB) (Miller, 2001), trackd, and Open-DIS (McGregor et al., n.d.) APIs. One instance of the IAE is run for each listener/user in a VE. To support multichannel voice communications between subjects in real-time, we use an implementation of DIS radio communications PDUs. DIS radio PDUs are an implementation of voice over IP that works within the DIS protocol definitions. The audio display was implemented to also support audio annotation (Brungart, 2012). The DIS radio integration includes receiving and playback support built directly into the IAE and a simple separate application just for the transmitting of DIS radio messages over the network. This application was built in C++/C# using the Open-DIS API.

2.2.3 Experiment Control - IC

The IC is an application to coordinate and trigger all the necessary components needed to run an experiment at one or both sites from a single computer console. This software provides an interface that allows experimenters easy control of experiment execution while minimizing opportunities for human error. The IC communicates with the other IVP components using DIS control PDUs we developed and can be run from either site. Our current version is a state-based system that executes one command at a time while maintaining a listening thread to collect messages from other components in the IVP and process them via interrupts. It was written in C++ using the VR-Link API and uses an XML configuration file for saving and loading experiments (VT Mäk, n.d.).

2.2.4 Artificial Agents and Scenarios

Frequently, experiments require the presence of artificial entities in the virtual world, which interact with each other and the users. Whether they are human entities, vehicles, or aircraft, we need a platform for generating and controlling the artificial intelligence (AI) of the entities in the IVP. To accomplish this we utilize VR-Forces and B-HAVE software (VT Mäk, n.d.). This software provides a robust platform for the development of scenarios with scripted and random AI agents who can interact with the users through the DIS/HLA protocols. VR-Forces is also customizable and extensible and we took advantage of this to create a custom version of its graphical user interface (GUI) that includes a Push-to- Talk feature, which creates a sound entity whenever the user clicks on the GUI's map of the virtual world at the location specified. This sound entity can then be associated with a live DIS radio channel or a stored sound file in the IAE. We also created several VR-Forces plug-ins that add a custom entity type for hostiles disguised as civilians, trigger scenario end events, and a random scenario generator.

2.2.5 Data Collection

Whenever human performance is examined, orderly data collection and analysis is critical to the success of the research. To facilitate this, we use a two-tiered approach. First, we want to collect a record of the entire experiment that allows programmers to revisit particular situations in order to evaluate problems and allows scientists to evaluate post hoc questions. To do this, we use the Mäk Data Logger application and employ only DIS or HLA as our network protocols to make sure all data are logged (VT Mäk, n.d.). A COTS solution, the Mäk Data Logger provides a DIS/HLA message logger that can be remotely controlled via a C++ API and allows a sequence of trials to be "replayed" in its entirety, including both program execution and users' responses. The second part of our data collection strategy is experiment-specific and addresses the a priori questions posed by the scientist. We implement this via a set of custom data collection C++ classes built into the IVE application. The data are collected into binary files that can be manipulated and exported into ASCII compatible files via a small utility we developed. In the future, we are looking towards a database-based system that would use MySQL or an equivalent product to store the large data sets and provide standard access methods for the analysis processes, with the ongoing goal of improving the data collection and analysis workflow to make the production of statistical and graphical results as efficient and painless as possible.

3. SPECIFIC METHODS AND RESULTS FROM EXAMPLE RESEARCH APPLICATIONS

3.1 Auditory Cueing in a Visual Search Task

Early research in the VERITAS facility included auditory- aided visual search tasks inside of the CAVE. We did not have the SLAB API for 3D audio so we used a custom DSP hardware solution (3d Gen) developed by Veridian, Inc., that interfaced with a custom Vega application via a serial port. In this experiment, the subject stood in the middle of the CAVE surrounded by a virtual cylinder of letters, as shown in Fig. 2. Their task was to locate, as rapidly as possible, a target letter in a field of distractors (Fig. 2). In the "feature" search condition, the target had a unique feature (e.g., a straight line segment as when searching for a P in a field of O's). In the "conjunction" search condition, the subject had to find a target with a particular combination of features that were not unique (e.g., searching for an R in a field of Q's and P's; Note that the "R" shares features with both the Q and the P.). The feature search is sometimes called a "pop out" search because it can be performed so rapidly. The conjunction search is much more difficult. As shown in Figure 3, response times are rapid and almost independent of the number of distractors in the feature search condition. Under the conjunction search condition without audio, performance degrades rapidly as the number of distractors increases; when a 3D audio cue is introduced, performance in the conjunction search condition returns to levels near those with the feature search. These results indicate that 3D audio cues can dramatically increase search performance in complex visual environments like those considered in

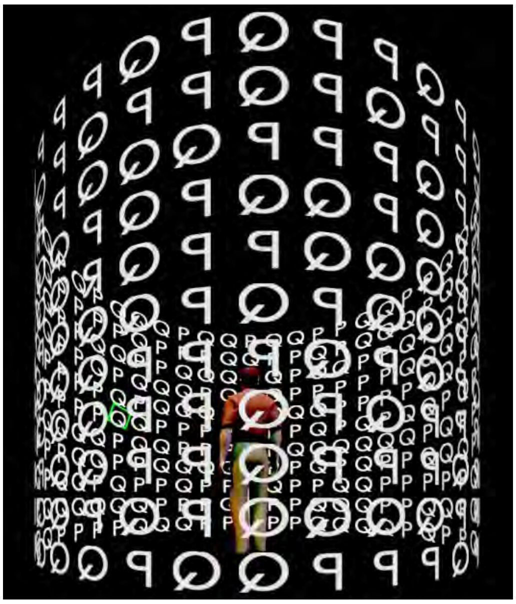

Figure 2. Diagram of the conjunction search condition, in which, the listener is surrounded by letters consisting of one target and multiple.

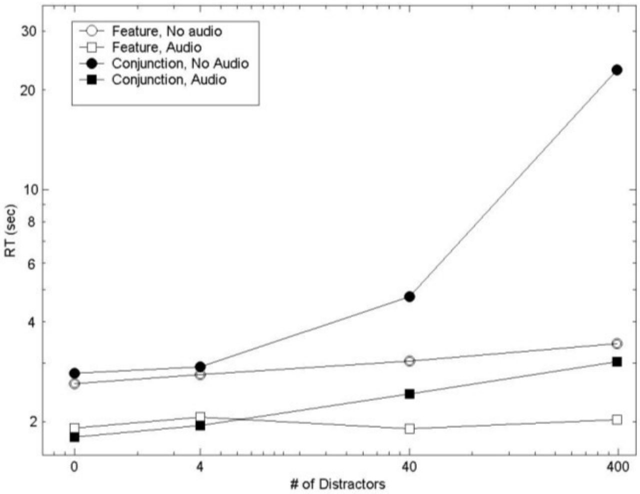

Figure 3. Results of the auditory aided visual search experiment

3.2 3D Audio Cueing in General Aviation

Although modern general aviation (GA) Traffic Advisory Systems (TAS) have decreased the frequency of mid-air collisions, such mishaps are still serious safety concerns for GA flight operations. To address this problem, we examined the benefits of using 3D audio cues to indicate airborne traffic to a GA pilot in a flight simulation implemented in the VERITAS CAVE (Fig. 4). We conducted this experiment prior to our development of the IVP, so a custom application specific to this task was developed. To create accurate virtual aircraft instruments we used GL Studio software and the corresponding Vega Prime plugin along with Vega Prime (GL Studio, n.d.). The task required participants to use a TAS display to visually acquire and identify targets appearing from various directions relative to their own. Response times, shown in Figure 5, were faster when 3D audio cues were provided than they were in the other two conditions, even when, as in the TAS+clock coordinate condition, semantic information was provided indicating the direction of the target. These results have clear implications for aviation safety (Simpson et al., 2004).

Figure 4. Screen capture of the visual scene from the point of view of the subject sitting in a virtual cockpit; note the visible target, a downward pointing arrow.

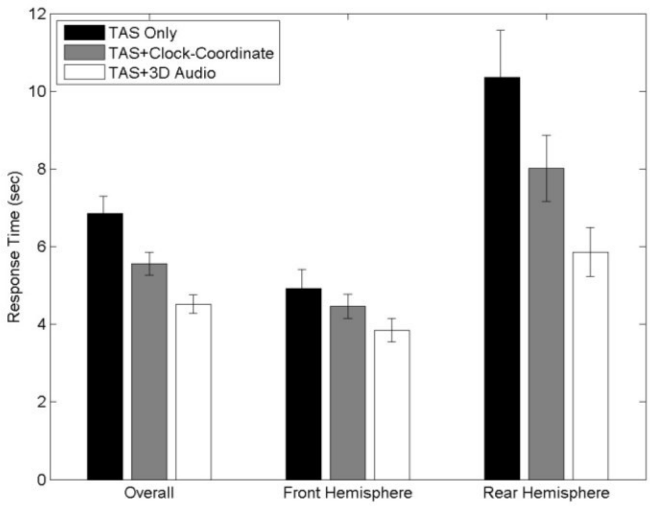

Figure 5. Response times plotted as a function of the direction of the target for each display condition in each display condition. The leftmost cluster of bars depicts the overall means averaged across all subjects and target locations; the middle and rightmost clusters show the results when the target originated from a location in the front and hemispheres, respectively. Error bars represent ±1 standard error (Simpson et al., 2004).

3.3 Team Navigation Threat Avoidance Task

A team navigation task in the IVP was used to evaluate how 3D audio communications might help ground soldiers maintain awareness of each other's locations in complex environments. In this task, subjects had to rendezvous as quickly as possible from different, unknown starting locations in large, unfamiliar, urban virtual environments (Fig. 6). Task performance between traditional monaural communications and 3D audio communications were compared. In the 3D audio condition, talkers could make their communications sound like they arose from their own location or from the location of another object in the environment. This latter implementation is known as audio annotation (Brungart, 2012). Rendezvous times, shown in Figure 7, were significantly shorter in the 3D audio condition, ($F(1,232) = 20.77$, $p < .0001$, M(3D audio) = 162.36 s, M(monaural) = 200.78 s (Hampton et al., 2012).

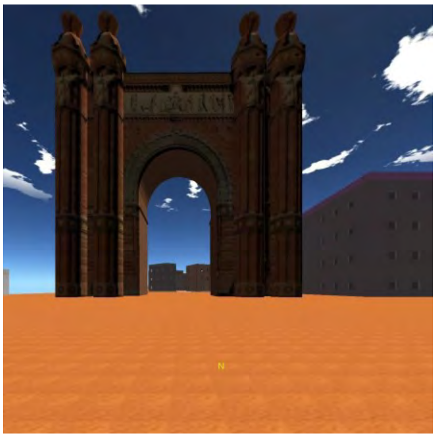

Figure 6. Screen shot of a scene from the virtual urban environment developed for the team navigation task.

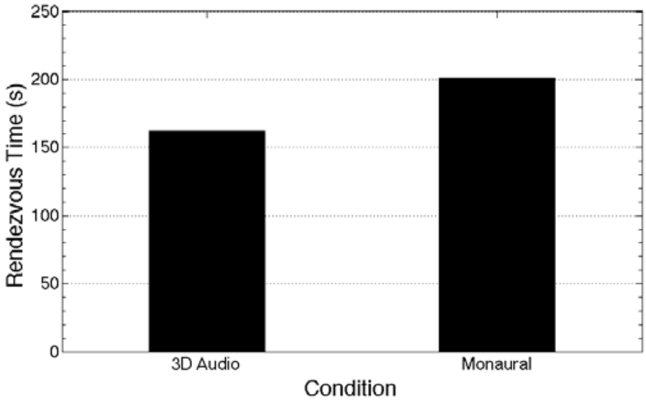

Figure 7. Average time to complete the rendezvous task in the 3D audio condition and the monaural condition.

3.4 Threat Acquisition Task

Many of today's military operations take place in large urban environments, which present unique challenges due to limited line of sight and increased concealment for enemy forces. This IVP experiment evaluated the potential of a 3D audio display to aid threat detection and localization in a complex visual environment. In this task, subjects rode as part of a virtual convoy through a simulated city in which they encountered snipers surrounded by distracting personnel (Fig. 8). We compared 3D audio cues to verbal semantic descriptions of the sniper's location and to simple audio warnings indicating the presence of a sniper. Consistent with the results described in Section 3.2, research, subjects located the sniper more quickly in the 3D audio condition compared to both the semantic description and simple warning conditions, ($F(2,10) = 9.07$, $p < .0057$, 3D Audio: M= 6.61 s, SD=6.45 s, Semantic: M= 9.19 s, SD=6.57 s, Monaural: M= 11.474 s, SD=10.12 s. (Fig. 9) (Robinson et al., 2012).

Figure 8. Screen shots of the subject's view in a trial from the threat acquisition task. Images of the left, front, and right walls of the CAVE are flattened out into a single image.

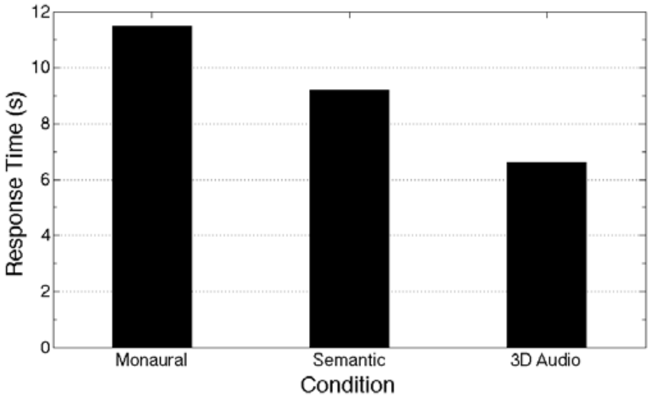

Figure 9. Time to acquire and neutralize the sniper under each of the three audio warning conditions.

4. CONCLUSION

The experiments, experiences, and results presented here provide an example of a VE platform being actively used for human performance experimentation. The success of the research we have completed suggests that immersive virtual environments are useful tools in investigating complex human performance tasks. In some cases, a VE platform can support research that might not be affordable or safe if done in the real world. Moreover, a VE platform can be used to record data sets that are far more detailed than what is feasible in most real world experiments.

In the future, development for the IVP will focus on several key areas: improving data collection and analysis workflows, reducing our reliance on high-cost licensed software, and building an even more robust and easy-to-use experiment control application. New low-cost tracking solutions that we are investigating, like the Microsoft Kinect, present an opportunity to integrate basic skeletal tracking into our applications. Our team is investigating the possible shift to a database solution for data collection and incorporating a network accessible database into the entire data workflow, from collection to final analysis. Weighing the cost and the development time needed to implement the features we need, we are working to replace several parts of the IVP's licensed software with open source solutions, including upgrading the IVE to increase visual fidelity and realism. Finally, each experiment conducted in this facility adds to our experience in how best to setup and control experiments via a dedicated application and we continue to refine and add features to our experiment control software.

The VERITAS facility and the IVP are the result of many years of iterative software and hardware development by a small team of computer scientists, engineers, and psychologists. Employing this interdisciplinary team throughout the development process has helped to ensure that these systems are robust and flexible enough to meet the needs of human performance researchers.

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